



ORIGINAL ARTICLE

In vitro evaluation of the marginal fit of different all-ceramic crowns



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Abstract *Background/purpose:* The marginal fit of all-ceramic restorations is a very important criterion for their long-term success. The aim of this *in vitro* study was to compare the marginal adaptation of crowns fabricated with four different all-ceramic systems using an image analysis method.

Materials and methods: A standardized all-ceramic preparation was made on a stainless steel die. Eighty gypsum dies were duplicated from this die and randomly divided into four groups of 20 each. Cerec 3, In-Ceram, IPS Empress 2, and Celay crowns were fabricated on dies of each group following the manufacturers' instructions. Marginal gaps of the crowns were evaluated without cementation on their own gypsum dies and then on the master die with a stereomicroscope and image analysis program. Two-way analysis of variance and Tukey's honest significant difference tests were used to evaluate the data ($\alpha = 0.01$).

Results: Mean gap dimensions and standard deviations at the marginal opening of the crowns evaluated on the gypsum dies were $21.5 \pm 4 \mu\text{m}$ for Celay, $29.3 \pm 5 \mu\text{m}$ for IPS Empress 2, $33 \pm 4 \mu\text{m}$ for Cerec 3, and $74.6 \pm 10 \mu\text{m}$ for In-Ceram crowns. Mean gap dimensions and standard deviations at the marginal opening of crowns evaluated on the master steel die were $27.8 \pm 4 \mu\text{m}$ for Celay, $41.5 \pm 7 \mu\text{m}$ for IPS Empress 2, $47.4 \pm 5 \mu\text{m}$ for Cerec 3, and $94.9 \pm 10 \mu\text{m}$ for In-Ceram crowns. Marginal opening values measured on the master die were higher than those of gypsum dies.

Conclusion: In-Ceram all-ceramic crowns showed the largest marginal gap, and Celay crowns showed the smallest marginal gap in both die groups. The marginal discrepancies found in this study were all within the clinically acceptable standard of $120 \mu\text{m}$.

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Introduction

Aesthetic dentistry has become increasingly important in recent years, and the demand for all-ceramic dental restorations by patients and professionals has enormously increased.^{1–7} All-ceramic dental restorations provide aesthetics and biocompatibility seldom rivaled by metal–ceramic restorations.^{8–12} Different techniques are used to fabricate crowns of all-ceramic systems. The IPS Empress 2 layering technique uses a heat-press method to produce a high-strength core of lithium-disilicate glass.^{6,8} Conventional In-Ceram crowns are fabricated using a slip-casting technique to produce a high-strength core. The slip-cast alumina is first partially sintered in a furnace to produce a porous framework that is then infiltrated with liquid glass in a second firing process.^{2,4,6,8,13} The Celay system provides an interesting manufacturing innovation with a convincing technique and easily performed skills; it facilitates the reproduction of individually formed resin models in industrially prefabricated ceramics using a manually controlled copy milling system.^{4,6} In the Cerec 3 system, which is a computer-aided design/computer-aided manufacturing all-ceramic system, a charge-coupled device camera is used to take a three-dimensional image of the abutment tooth from the occlusal side, and the ceramic material is milled on the basis of these optical data.^{12–14} It is advantageous to fabricate all-ceramic crowns with this system in only one appointment and in <1 hour.¹⁵

The marginal fit of all-ceramic restorations is one of the important criteria used in clinically evaluating their long-term success. The presence of marginal discrepancies in a restoration exposes the luting agent to the oral environment. The marginal opening allows more plaque accumulation which can initiate gingival inflammatory reactions and may lead to deterioration of the soft tissues due to periodontal disease. It also causes recurrent caries and bone loss.^{6,8,16–20} Many studies evaluated the marginal fit of different all-ceramic crowns.^{2,4,6,8,21–28} The results show great variations within a single crown system. Evaluating the marginal discrepancy of crowns depends on several factors: the measurement of cemented or noncemented crowns, the type of abutment used for the measurements, the type of microscope, the enlargement factor used for the measurement location, and the quantity of single measurements.²⁷ There are variations as to what a clinically acceptable margin is.²⁹ McLean and von Fraunhofer³⁰ proposed that a restoration will be successful if marginal gaps and cement thicknesses of < 120 µm can be achieved. Tuntiprawon and Wilson³¹ found that ceramic crowns with smaller gap dimensions at the axial wall and marginal opening demonstrated the best compressive strengths when loaded on dies.

The purpose of this study was to compare the marginal fit of four different all-ceramic single anterior crowns on gypsum working dies and master steel dies using an optical microscope with image analysis software.

Materials and methods

A steel master die simulating an idealized maxillary incisor preparation for all-ceramic crown treatment was fabricated

according to the following guidelines: 8 mm in height, a 1.2-mm-wide margin with a 90° shoulder finish line, 6° of axial wall convergence, and palatal concavity (Fig. 1).

Manufacture of working dies

In total, 80 polyvinyl siloxane impressions (Imprint II Garant; 3M ESPE, St. Paul, MN, USA) were made from the master steel die, and type IV dental stone (Begostone plus; BEGO Bremer Goldschlägerei Wilh. Herbst, Bremen, Germany) was poured in. The dies were randomly divided into four groups of 20 dies each: 20 Cerec 3 crowns, 20 In-Ceram alumina crowns produced by slip-casting, 20 IPS Empress 2 crowns using a layering technique, and 20 copy-milled Celay feldspathic crowns were fabricated according to their manufacturer's instructions. Each group of crowns was fabricated by an experienced person who was accustomed to the specific system.

Manufacture of Cerec 3 crowns

Optical impressions were taken with a charge-coupled device camera on the working dies using Cerec 3 (Sirona Dental Systems, Bensheim, Germany), and crowns were milled from ceramic blocks (Vita Blocks Mark II; VITA Zahnfabrik H. Rauter, Bad Sackingen, Germany). The cement space was adjusted to 0 µm, because a setting of "0" will allow for 40–50 µm of space for cementation in the Cerec 3 system. In total, 20 crowns were fabricated. Then, a silicon key was created from one of the Cerec 3 crowns to fabricate standardized crowns. The other crowns were fabricated using this silicon key.

Manufacture of In-Ceram crowns

In-Ceram crowns were fabricated according to the manufacturer's instructions. After placing three layers of die spacers, the working dies were duplicated with condensation silicon (Zetaplus, Zhermack, Rovigo, Italy) to produce the special plaster (In-Ceram Spezial Plaster; VITA Zahnfabrik H. Rauter) models. After covering the models with slip-cast alumina to form the crown substructures, they



Figure 1 Steel master die.

were sintered for 10 hours at 1120°C in an In-Ceram 3 (VITA Zahnfabrik H. Rauter) special furnace. For glass infiltration, models were fired for 4 hours at 1100°C. After this process, the core was adjusted to 0.5 mm thick. Crowns were then fabricated with Vitadur alpha (VITA Zahnfabrik H. Rauter) using the silicon key.

Manufacture of IPS Empress 2 crowns

IPS Empress 2 crowns were fabricated according to the manufacturer's instructions. Two layers of die spacers were applied up to 1 mm from the crown margin for the layering technique. Wax patterns of the substructures were created. An axial sprue was attached, and then wax patterns were placed in a special investment material (Ivoclar Vivadent AG, Schaan, Liechtenstein). The wax was eliminated in a burnout furnace preheated to 850°C with an alumina plunger for 90 minutes. The IPS Empress 2 ingots became softened at 920°C and were automatically pressed into the mold in a furnace (EP 600, Ivoclar Vivadent AG). After pressing and cooling, specimens were divested, cleaned, dried, and abraded with airborne particles. Then, feldspathic ceramic was applied to the substructure using the silicon key.

Manufacture of Celay crowns

Resin patterns were fabricated using the silicon key on the working dies. The structures were scanned using the Celay system (Mikrona Technologie AG, Spreitenbach, Switzerland) and milled from feldspathic ceramic (Vita Celay Blanks, VITA Zahnfabrik H. Rauter). After the milling process, specimens were removed from the vise and finished.

Measurements

The marginal fit of each restoration was examined using a digital zoom microscope (SMZ 1500; Nikon Europe BV, Badhoevedorp, the Netherlands). First, measurements were made on gypsum dies. For all measurements, the crowns were fixed on the dies with a small amount of provisional dental cement and placed on the palatal incisal edge of the die using a dental probe as in a previous study.⁴ Crowns were not cemented. Measurements were made parallel to the gap between the external edge of the structure and the preparation limit. Four digital images were taken of the buccal, mesial, lingual, and distal surfaces of each crown using a Nikon camera (Nikon Coolpix 5000; Nikon Europe BV). Images of the gaps were examined using digital image analysis software (Clemex Vision Lite 3.5; Clemex Technologies, Longueuil, Canada). Twenty measurements were made of each surface of each crown. Fig. 2A shows the marginal gap of an all-ceramic crown at three points on a gypsum die. These procedures were repeated using the master steel die instead of the gypsum die for each crown. Fig. 2B shows the marginal gap of an all-ceramic crown at three points on the master steel die. The marginal fit of the crown was defined as a mean value of the 80 measurements for each crown.

Statistical analysis

A two-way analysis of variance (ANOVA) was computed for statistical significance among two variables, and Tukey's honest significant difference (HSD) test was used to evaluate the significant difference between interactions ($\alpha = 0.01$). For each die group, statistical interferences among the groups were made using a one-way ANOVA ($\alpha = 0.01$). A *t*-test was carried out to evaluate the significant difference between the two die groups. A criterion of 120 μm was used as the maximum clinically acceptable marginal opening in this study.

Results

The two-way ANOVA revealed significant differences among the all-ceramic systems and die groups ($P < 0.01$) (Table 1). The *t*-test showed that values of the marginal gap on the master die were significantly higher than that of the gypsum dies. The one-way ANOVA test showed significant differences among the crown groups for gypsum dies. Tukey's HSD test revealed that the In-Ceram group ($74.6 \pm 10 \mu\text{m}$) possessed a significantly larger marginal opening than the other groups, there were no significant differences between IPS Empress 2 ($29.3 \pm 5 \mu\text{m}$) and Cerec 3 crowns ($33 \pm 4 \mu\text{m}$), and Celay crowns showed the smallest marginal gap ($21.5 \pm 4 \mu\text{m}$) ($P > 0.01$) (Fig. 3). Table 2 shows the mean, minimum, and maximum marginal opening values and standard deviations (SDs) of the average marginal gap of the crown groups on the gypsum dies.

The one-way ANOVA test showed that there were significant differences among all-ceramic systems on the master steel die ($P < 0.01$). Mean values and SDs of the marginal fit were $27.8 \pm 4 \mu\text{m}$ for the Celay group, $41.5 \pm 7 \mu\text{m}$ for the IPS Empress 2 group, $47.4 \pm 5 \mu\text{m}$ for the Cerec 3 group, and $94.9 \pm 10 \mu\text{m}$ for the In-Ceram group (Table 3, Fig. 3).

For both dies, Celay crowns had significantly better marginal fit than the other crowns, and the In-Ceram group exhibited significantly greater marginal openings than the others.

Discussion

Marginal accuracy is an important quality criterion for fixed prosthodontics.²⁷ Many studies examined the marginal fit of crowns,^{2,4,6,8,12,21,27} and the authors used steel or resin dies to measure the marginal accuracy in many of those studies.^{2,4,8,12} Natural teeth show large variations because of their age, individual structures, and storage time after extraction, thus causing difficulties in obtaining standardized abutments.²⁷ The advantage of this method is the possibility of achieving a standardized preparation for all crown systems. The master steel die remained clear and free of damage, which was an additional advantage.⁴

An important factor in the literature is the cementation of crowns before evaluating the marginal fit. Many authors analyzed cemented crowns.^{3,7,26,27} The marginal gap generally increases after luting, which is clinically relevant.^{7,27} But

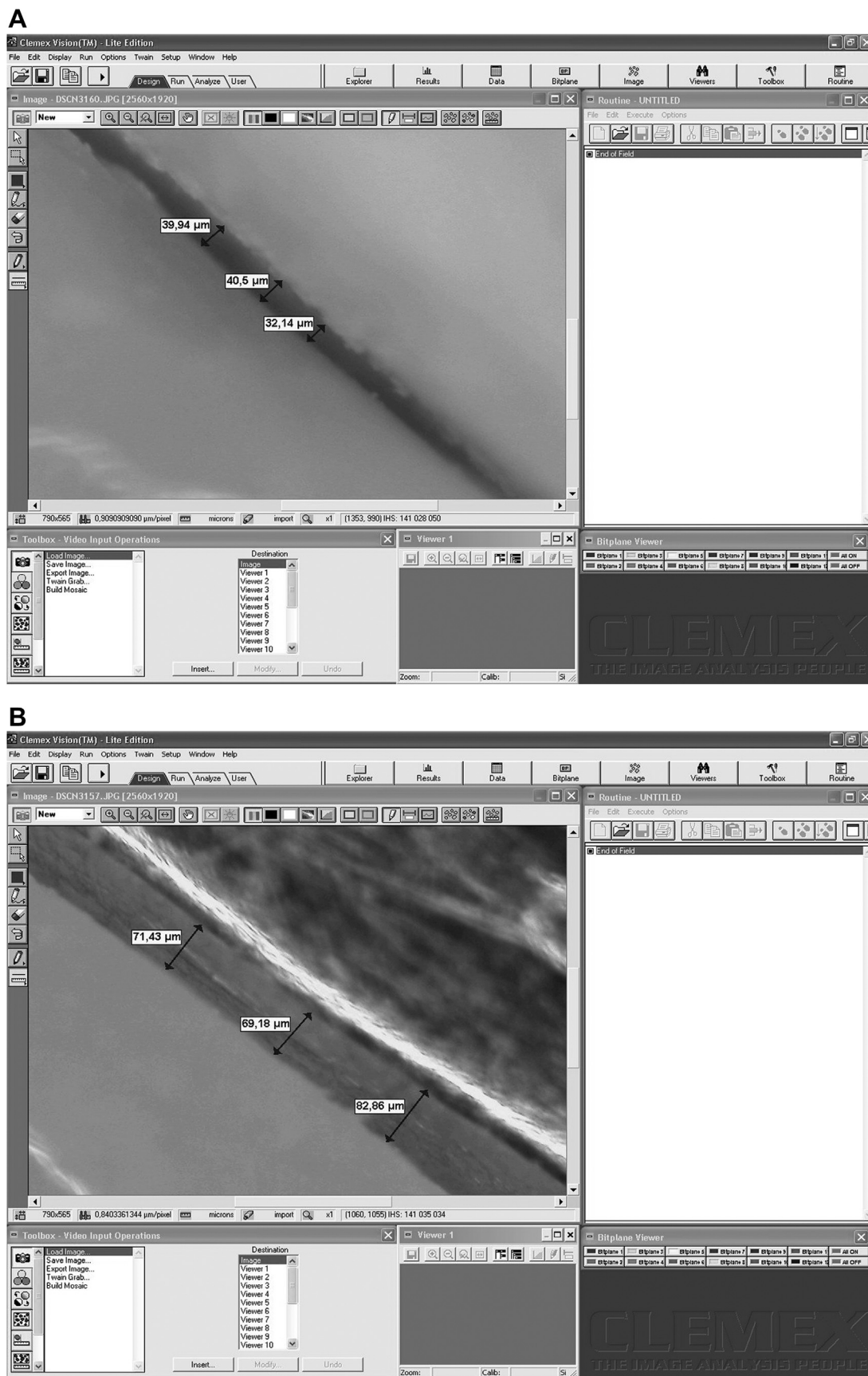


Figure 2 (A) The marginal gap of an all-ceramic crown at three points on gypsum dies. (B) The marginal gap of an all-ceramic crown at three points on the master steel die.

Table 1 Results of two-way analysis of variance.

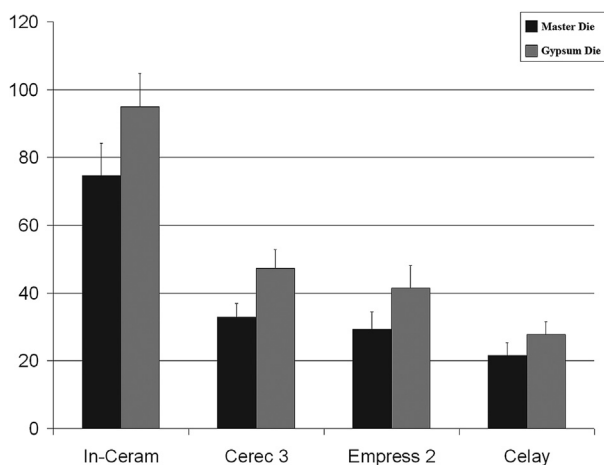
Source	df	Sum of squares	Mean square	F	P
Ceramic type (A)	3	84,009.91	28,003.29	669.69	0.000
Die (B)	1	7090.24	7090.24	169.56	0.000
A*B	3	992.52	330.84	7.19	0.000

additional systematic and statistical faults are introduced due to cementation.⁴ For this reason, cementing procedures were avoided in this study. All measurements were performed by the same investigator to avoid an increase in statistical error.

Measurements of the marginal fit are often accomplished by sectioning a crown and measuring it with a light microscope or a scanning electron microscope. However, this method has the potential for artifactual distortion, provides only limited numbers and positions of measurements, and is destructive.¹⁹ In the present study, a direct measuring technique under a microscope with image analysis software permitted nondestructive quantification and multiple measurements.

Nonetheless, there were several limitations to this study. Some researchers evaluated the internal fit of the crowns,^{12,17} but measuring the internal fit of crowns in this study was impossible, because measuring the internal fit of the crowns requires cementing the crowns and sectioning the specimens. Another limitation of this study was that before the microscopic measurement, the marginal gap was oriented perpendicularly and orthoradially on the computer monitor. However, precise positioning of a specimen was difficult because the measurements could only be visually controlled by the researcher.²⁷ Furthermore, examination of the marginal fit without cementation of crowns in this study did not completely simulate clinical conditions.

The sample size and number of measurements per specimen are important factors. Some authors selected six²⁴ or eight¹⁷ specimens for each group. Many authors designed studies using 10 specimens per group.^{2,4,8,26} In most earlier studies, only 4 ± 2 locations were evaluated at the margin of each crown specimen/abutment.^{8,32–35} However, some authors^{32,36} made measurements at

**Figure 3** Marginal gap values and SDs of the groups on master and gypsum dies.**Table 2** The mean, minimum, and maximum values and SDs of the average marginal gap of the crown groups on the gypsum dies (μm).

Groups	n	Min	Max	Mean	SD	Tukey HSD
Cerec 3	20	24.3	40.9	33	4.0	a
In-Ceram	20	61.5	94.1	74.6	9.6	b
IPS-Empress 2	20	18.3	40.2	29.3	5.1	a
Celay	20	16.7	33.5	21.5	3.8	c

n = number; Min = minimum; Max = maximum; SD = standard deviation.

multiple reference points, with small distances between each, resulting in 18–150 measurements for a single specimen/abutment. Other authors^{6,21} randomly selected points along the margin of the crown with no specific locations and calculated the mean of all measurements for the marginal fit of the crown. Groten et al¹⁶ suggested that, ideally, 50 or at least 20–25 measurements are required to obtain clinically relevant information about the gap size. In this study, 20 crowns for each group were prepared and 80 measurements were made per crown to improve the statistical accuracy.

It is possible to improve the seating of a crown only if internal relief is sufficient to accommodate the luting agent. Internal relief must accommodate the cement layer and any irregularities on the tooth and inner crown surface.³⁷ In the present study, die spacers were applied according to the manufacturer's instructions.

Yeo et al⁶ reported that the marginal openings of In-Ceram and IPS Empress 2 crowns were 112 and 46 μm, respectively, which is in agreement with the results of this study. Sulaiman et al⁸ evaluated the marginal gap of In-Ceram crowns and found it to be 160.66 μm. Those results are also in accordance with this study. However, Rinke et al² reported a marginal gap of 33.5 μm for In-Ceram crowns.

An explanation for the lack of agreement may be the variations in the methods used by different investigators studying marginal accuracy.⁶ Sulaiman et al⁸ suggested that the cause could be the use of different measuring instruments. The skill of a dental technician who made the restorations is also an important factor.⁶

The reason why the In-Ceram crowns showed the largest marginal gap in this study may have been related to two factors. First, during glass infiltration firing, the glass

Table 3 The mean, minimum, and maximum values and SDs of the average marginal gap of the crown groups on the master steel die (μm).

Groups	n	Min	Max	Mean	SD	Tukey HSD
Cerec 3	20	39.1	56.1	47.4	5.4	a
In-Ceram	20	74	116.5	94.9	9.9	b
IPS-Empress 2	20	29.4	54.7	41.5	6.6	c
Celay	20	21	35.1	27.8	3.8	d

n = number; Min = minimum; Max = maximum; SD = standard deviation.

mixture tends to settle, which creates an excessive bulk at the margin of the coping after the firing is completed and must be trimmed using a rotary instrument. Careless removal of excess material at the margin could potentially lead to increased marginal discrepancy.⁸ The second reason may be the need for an additional second impression from gypsum dies to prepare a slip-casting. A dimensional change might have occurred due to these procedures.

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References

- Siervo S, Bandettini B, Siervo P, Falleni A, Siervo R. The Celay system: a comparison of the fit of direct and indirect fabrication techniques. *Int J Prosthodont* 1994;7:434–9.
- Rinke S, Hüls A, Jahn L. Marginal accuracy and fracture strength of conventional and copy-milled all-ceramic crowns. *Int J Prosthodont* 1995;8:303–10.
- Gemalmaz D, Özcan M, Yoruç AB, Alkumru HN. Marginal adaptation of a sintered ceramic inlay system before and after cementation. *J Oral Rehabil* 1997;24:646–51.
- Groten M, Girthofer S, Pröbster L. Marginal fit consistency of copy-milled all-ceramic crowns during fabrication by light and scanning electron microscopic analysis in vitro. *J Oral Rehabil* 1997;24:871–81.
- Hwang JW, Yang JH. Fracture strength of copy-milled and conventional In-Ceram crowns. *J Oral Rehabil* 2001;28:678–83.
- Yeo IS, Yang JH, Lee JB. In vitro marginal fit of three all-ceramic crown systems. *J Prosthet Dent* 2003;90:459–64.
- Naert I, van Der Donck A, Beckers L. Precision of fit and clinical evaluation of all-ceramic full restorations followed between 0,5 and 5 years. *J Oral Rehabil* 2005;32:51–7.
- Sulaiman F, Chai J, Jameson LM, Wozniak WT. A comparison of the marginal fit of In-Ceram, IPS Empress and Procera crowns. *Int J Prosthodont* 1997;10:478–84.
- McLaren EA, White S. Survival of In-Ceram crowns in a private practice: a prospective clinical trial. *J Prosthet Dent* 2000;83:216–22.
- McLaren EA, Terry DA. CAD/CAM systems, materials and clinical guidelines for all-ceramic crowns and fixed partial dentures. *Compend Contin Educ Dent* 2002;23:637–53.
- Bindl A, Mörmann WH. An up to 5-year clinical evaluation of posterior In-Ceram CAD/CAM core crowns. *Int J Prosthodont* 2002;15:451–6.
- Nakamura T, Dei N, Kojima T, Wakabayashi K. Marginal and internal fit of Cerec 3 CAD/CAM All-Ceramic crowns. *Int J Prosthodont* 2003;16:244–8.
- Pröbster L. Survival rate of In-Ceram restorations. *Int J Prosthodont* 1993;6:259–63.
- Mörmann WH, Bindl A. All ceramic, chair side computer aided design/computer aided machining restorations. *Dent Clin North Am.* 2002;46:405–26.
- Morin M. CEREC: the power of technology. *Compend Contin Educ Dent* 2001;22:27–9.
- Groten M, Axmann D, Pröbster L, Weber H. Determination of the minimum number of marginal gap measurements required for practical in vitro testing. *J Prosthet Dent* 2000;83:40–9.
- Oruç S, Tulunoğlu İ. Fit of titanium and a base metal alloy metal–ceramic crown. *J Prosthet Dent* 2000;83:314–8.
- Ushiwata O, Moraes JV. Method for marginal measurements of restorations: accessory device for toolmakers microscope. *J Prosthet Dent* 2000;83:362–6.
- Mitchell CA, Pintado MR, Douglas WH. Nondestructive, in vitro quantification of crown margins. *J Prosthet Dent* 2001;85:575–84.
- Wolfart S, Wegner SF, Al-Halabi A, Kern M. Clinical evaluation of marginal fit of a new experimental all-ceramic system before and after cementation. *Int J Prosthodont* 2003;16:587–92.
- Chan C, Haraszthy G, Gerstorfer JG. The marginal fit of Cerestore full-ceramics crowns—a preliminary report. *Quintessence Int* 1985;6:399–402.
- Davis DR. Comparison of fit of two types of all-ceramic crowns. *J Prosthet Dent* 1988;59:12–6.
- Schaerer P, Sato T, Wohlwend A. A comparison of the marginal fit of three cast ceramic crown systems. *J Prosthet Dent* 1988;59:534–42.
- Weaver JD, Johnson GH, Bales DJ. Marginal adaptation of castable ceramic crowns. *J Prosthet Dent* 1991;66:747–53.
- Holmes JR, Sulik WD, Holland GA, Bayne SC. Marginal fit of castable ceramic crowns. *J Prosthet Dent* 1992;8:303–10.
- May KB, Russell MM, Razzoog ME, Lang BR. Precision of fit: the Procera AllCeram crown. *J Prosthet Dent* 1998;80:394–404.
- Beschmidt SM, Strub JR. Evaluation of the marginal accuracy of different all-ceramic crown systems after simulation in the artificial mouth. *J Oral Rehabil* 1999;26:582–93.
- Boening KW, Wolf BH, Schmidt AE, Kastner K, Walter MH. Clinical fit of Procera AllCeram crowns. *J Prosthet Dent* 2000;84:419–24.
- Hunter AJ, Hunter AR. Gingival margins for crowns: a review and discussion: part II. Discrepancies and configurations. *J Prosthet Dent* 1990;64:636–42.
- McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an in vivo technique. *Br Dent J* 1971;131:107–11.
- Tuntiprawon M, Wilson PR. The effect of cement thickness on the fracture strength of all-ceramic crowns. *Aust Dent J* 1995;40:17–21.
- Gonzalo E, Suarez MJ, Serrano B, Lozano JF. A comparison of the marginal discrepancies of zirconium and metal ceramic fixed dental prostheses before and after cementation. *J Prosthet Dent* 2009;102:378–84.
- Hung SH, Hung KS, Eick JD, Chappell RP. Marginal fit of porcelain-fused-to-metal and two types of ceramic crown. *J Prosthet Dent* 1990;72:585–90.
- Vigolo P, Fonzi F. An in vitro evaluation of fit of zirconium-oxide-based ceramic four-unit fixed partial dentures, generated with three different CAD/CAM systems, before and after porcelain firing cycles and after glaze cycles. *J Prosthodont* 2008;17:621–6.
- Goldin EB, Boyd 3rd NW, Goldstein GR, Hittelman EL, Thompson VP. Marginal fit of leucite–glass pressable ceramic restorations and ceramic-pressed-to-metal restorations. *J Prosthet Dent* 2005;93:143–7.
- Balkaya MC, Cinar A, Pamuk S. Influence of firing cycles on the margin distortion of 3 all-ceramic crown systems. *J Prosthet Dent* 2005;93:346–55.
- Grajower R, Lewinstein I. A mathematical treatise on the fit of crown castings. *J Prosthet Dent* 1983;49:663–74.